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MEMORANDUM

RESIDUAL FUEL EXPULSION FROM A SIMULATED
50,000-POUND-THRUST LIQUID-PROPELLANT ROCKET ENGINE
HAVING A CONTINUOUS ROCKET-TYPE IGNITER

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RESIDUAL FUEL EXPULSION FROM A SIMULATED
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SUMMARY

Tests have been conducted to determine the starting characteristics of a 50,000-pound-thrust rocket engine with the conditions of a quantity of fuel lying dormant in the simulated main thrust chamber. Ignition was provided by a smaller rocket firing rearwardly along the center line. Both alcohol-water and anhydrous ammonia were used as the residual fuel.

The igniter successfully expelled the maximum amount of residual fuel ($3\frac{1}{2}$ gal) in 2.9 seconds when the igniter was equipped with a sonic discharge nozzle operating at propellant flow rates of 3 pounds per second. Lesser amounts of residual fuel required correspondingly lower expulsion times. When the igniter was equipped with a supersonic exhaust nozzle operating at a flow of 4 pounds per second, a slightly less effective expulsion rate was encountered.

INTRODUCTION

At present, many problems are being anticipated and resolved in connection with the planned research flights of a hypersonic manned vehicle powered by a single-chamber, liquid-propellant, 50,000-pound-thrust rocket engine. Ignition is provided in this engine by a small two-stage rocket firing continuously along the center line of the main chamber. One of the requirements for the engine is that it must be capable of being started and restarted at altitude while in an approximately horizontal position. The propellants to be used in the main chamber are liquid oxygen and anhydrous ammonia.

The possibility of residual fuel lying in the chamber at the time of starting has been considered particularly for the case of in-flight restarts. The presence of such fuel at the time of main-chamber ignition might cause pressure surges, ignition delays followed by detonations, and

other undesirable and possibly hazardous conditions. It is believed that the igniter jet might be effective in expelling any residual fuel lying in the chamber, and the tests described herein were for the purpose of determining such expulsion characteristics. Admittedly, if a mixture of both fuel and oxidizer is lying dormant in the chamber, a disastrous explosion could be triggered by the igniter flame. However, such a condition would require a double malfunction and is much less probable.

At the request of the National Aeronautics and Space Administration, the Directorate of Missile Captive Test of the Air Force Flight Test Center, (DMCT), Edwards Air Force Base, Calif., conducted a series of tests to determine if an igniter firing into a thrust chamber containing a puddle of fuel would expel the residual fuel effectively and without serious detonation. The tests utilized a full-scale, simulated thrust chamber of the rocket engine and a residual fuel quantity varying from $\frac{2}{3}$ gallon to $3\frac{1}{2}$ gallons in the chamber at time of igniter start. Fuels tested were alcohol-water and anhydrous ammonia. The results of these tests are reported herein.

APPARATUS AND PROCEDURE

The simulated combustion chamber with the exhaust nozzle was mounted horizontally on one of the DMCT rocket-engine thrust stands. The basic dimensions of the chamber are: overall length, $42\frac{1}{2}$ inches; combustion-chamber diameter, $17\frac{3}{4}$ inches; throat diameter, $8\frac{5}{8}$ inches; nozzle-exit diameter, $19\frac{1}{8}$ inches. These dimensions produced a characteristic length for the combustion chamber closely simulating the characteristic length of the actual engine. The chamber could contain a maximum of $3\frac{1}{2}$ gallons of residual fuel. The igniter used was a single chamber of the LRB8-RM-6 rocket engine which was capable of operating over a propellant flow rate range of 3 to 4 pounds per second. The igniter was mounted at the injector end of the simulated chamber and fired rearward along the center line of the combustion chamber. The propellants used for the igniter were liquid oxygen and alcohol-water. Tests were made both with the igniter chamber's standard supersonic nozzle (convergent-divergent type) having a throat diameter of $2\frac{1}{2}$ inches, and with a modified sonic nozzle (convergent type) incorporating a $1\frac{1}{2}$ -inch-diameter throat. All tests

were conducted at ground atmospheric conditions. Figure 1 is a photograph of the test setup. A sketch of the simulated combustion chamber and the igniter is shown in figure 2.

The instrumentation consisted of three static-pressure pickups in the simulated chamber and a temperature-sensing element having an extremely fast response located in the combustion chamber. Flowmeters were used to measure the propellant flow rates. Photographic coverage provided high-speed color movies of each test, illustrating the color and flame intensity of the exhaust jet. The test procedure consisted of dumping a given amount of fuel into the simulated combustion chamber, then starting the igniter at total propellant flow rates of 3 to 4 pounds per second. Test runs were of 5 to 8 seconds duration.

RESULTS AND DISCUSSION

Continuous data of the test operation were provided by recording galvanometer and oscillograph equipment. Examination of these records disclosed the following information.

Figure 3(a) gives a typical time history of the static pressure within the simulated combustion chamber after ignition of the igniter rocket chamber. Fourteen tests were made with varying amounts of alcohol-water (11 runs) and anhydrous ammonia (3 runs) in the simulated chamber at ignition time. The igniter was normally operated at an oxidant-fuel ratio of 1.2. It is noted at igniter start that a momentary pressure surge occurs in the simulated chamber, never exceeding a measured value of 5 pounds per square inch, followed immediately by a lower-than-atmospheric pressure of -2 psi to -4 psi resulting from the aspirating effect of the exhaust jet stream. For these runs no serious pressure rise was encountered at the starting operation, even though the fuel puddle was exposed to a combustion-supporting atmosphere prior to igniter operation. The higher pressure surge shown in figure 3(b) occurred in only one run and resulted from a delayed start of the igniter, permitting a discharge of liquid oxygen at 175-psi manifold pressure for 0.65 second into the simulated chamber which contained 3.5 gallons of alcohol-water fuel mixture. As a result, firing the igniter into this oxygen-rich chamber produced a somewhat greater pressure rise than normal at the start. The maximum pressure recorded, 113 psi, is well below the designed operating chamber pressure of 600 psi for this engine. These data indicate that when residual fuel exists in the combustion chamber at time of igniter start, it does not constitute a hazard to the chamber structure if normal igniter operation occurs.

To determine the effectiveness of the igniter jet in purging residual fuel from the main combustion chamber, a fast-response thermocouple

was installed. When the thermocouple was covered by the residual fuel, it would measure the fuel temperature until successful purging exposed it to the jet stream of the igniter exhaust. Figure 4(a) is a time history of this temperature measurement for residual fuel quantities of $\frac{2}{3}$ gallon to $3\frac{1}{2}$ gallons with the igniter utilizing a supersonic nozzle.

It is noted that when $\frac{2}{3}$ gallon of anhydrous ammonia was used as the residual fuel, successful purging occurred at 0.8 second after the start of the igniter, as indicated by rapid increase in temperature at that time. Figure 4(b) is the results of these tests with a sonic nozzle installed in the igniter engine.

Figure 5 indicates the time required to expel a given quantity of residual fuel and is based on the data presented in the previous figure. It is noted that with the maximum quantity ($3\frac{1}{2}$ gallons) of residual fuel, 2.9 seconds were required for expulsion when the igniter was equipped with a sonic nozzle operating at a propellant flow rate of 3 pounds per second. This value compares with the slightly less effective time of 3.6 seconds when the igniter was equipped with a supersonic nozzle operating at a propellant flow rate of 4 pounds per second. Lesser amounts of residual fuel required correspondingly lower expulsion time.

In general, visual observation and use of high-speed color movies substantiated the time of expulsion as determined by temperature measurements. For a maximum residual fuel load ($3\frac{1}{2}$ gallons), the initial start was observed to be a heavy ball of red flame followed by approximately 3 seconds of a white exhaust jet, indicating rapid expulsion of the residual fuel in a liquid and vaporous condition. At 3 seconds, this jet changed to the usual red exhaust common to the rocket operation at proper propellant-mixture ratio.

SUMMARY OF RESULTS

To investigate the starting characteristics of a 50,000-pound-thrust rocket engine under the conditions of propellant fuel still remaining in the simulated main thrust chamber, tests were conducted on a full-scale simulated thrust chamber. Ignition was provided by a smaller rocket firing rearward along the center line. Both alcohol-water and anhydrous ammonia were used as residual fuel. The results obtained were:

1. The test data indicate that when residual fuel exists in the combustion chamber at time of igniter start, it does not constitute a hazard to the chamber structure since the maximum pressure rise that was recorded was well below the designed operating chamber pressure.

2. The igniter engine was capable of expelling the maximum amount $\left(3\frac{1}{2}\right)$ gallons of residual fuel in 2.9 seconds when equipped with a sonic nozzle operating at a propellant flow of 3 pounds per second. Lesser amounts of residual fuel required correspondingly lower expulsion times.

3. When the igniter was equipped with a supersonic exhaust nozzle operating at a propellant flow rate of 4 pounds per second, 3.6 seconds were required to expel $3\frac{1}{2}$ gallons.

High-Speed Flight Station,
National Aeronautics and Space Administration,
Edwards, Calif., October 31, 1958.

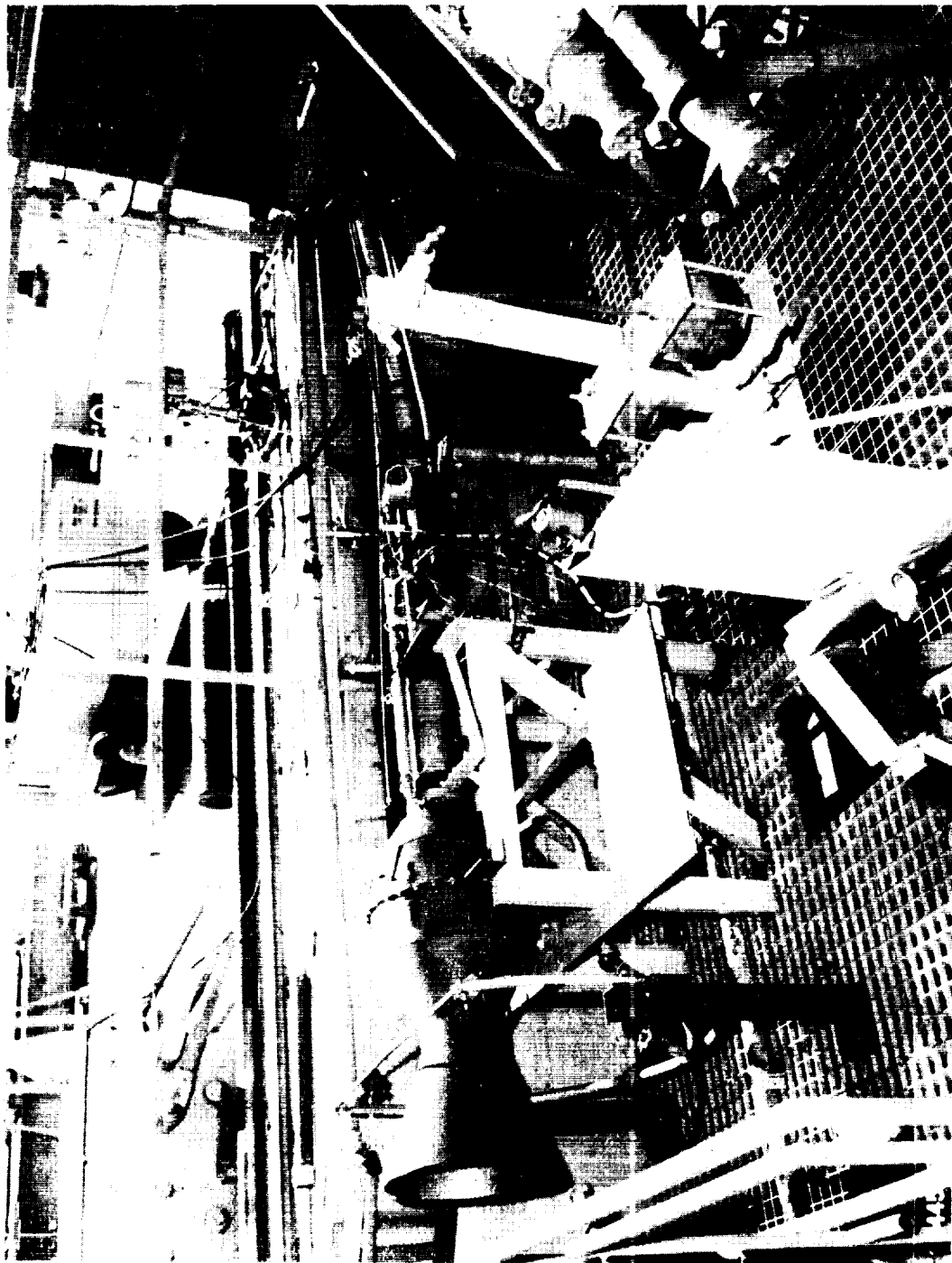


Figure 1.- Test-stand arrangement of full-scale simulated main thrust chamber
of 50,000-pound-thrust liquid rocket engine. E-9445 58

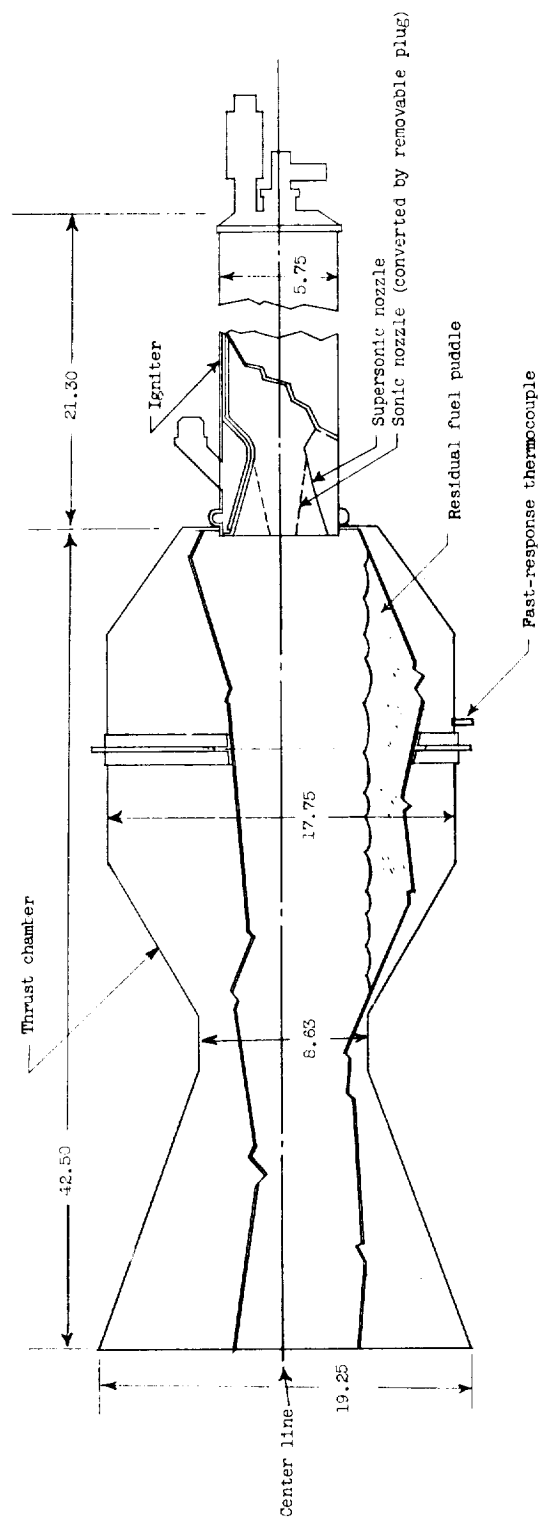
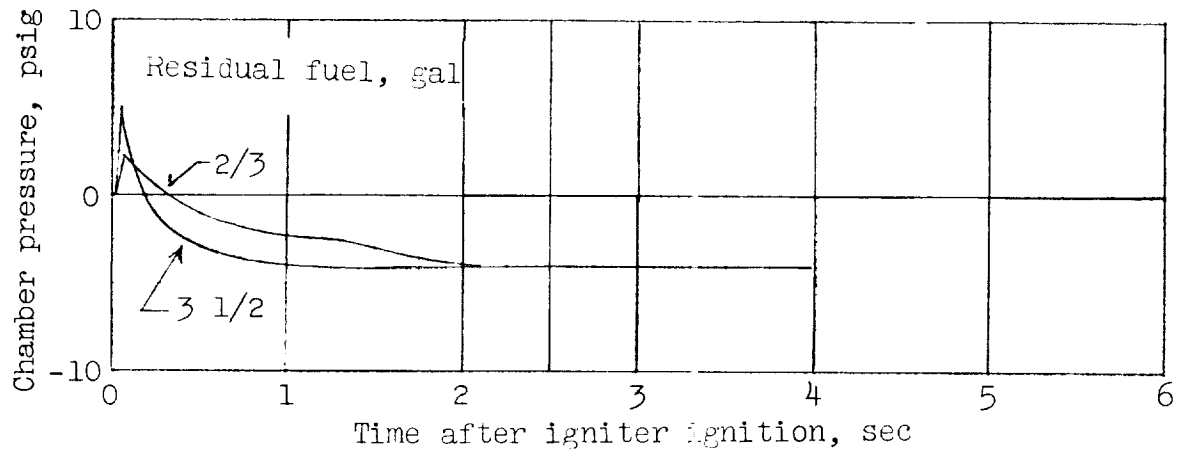
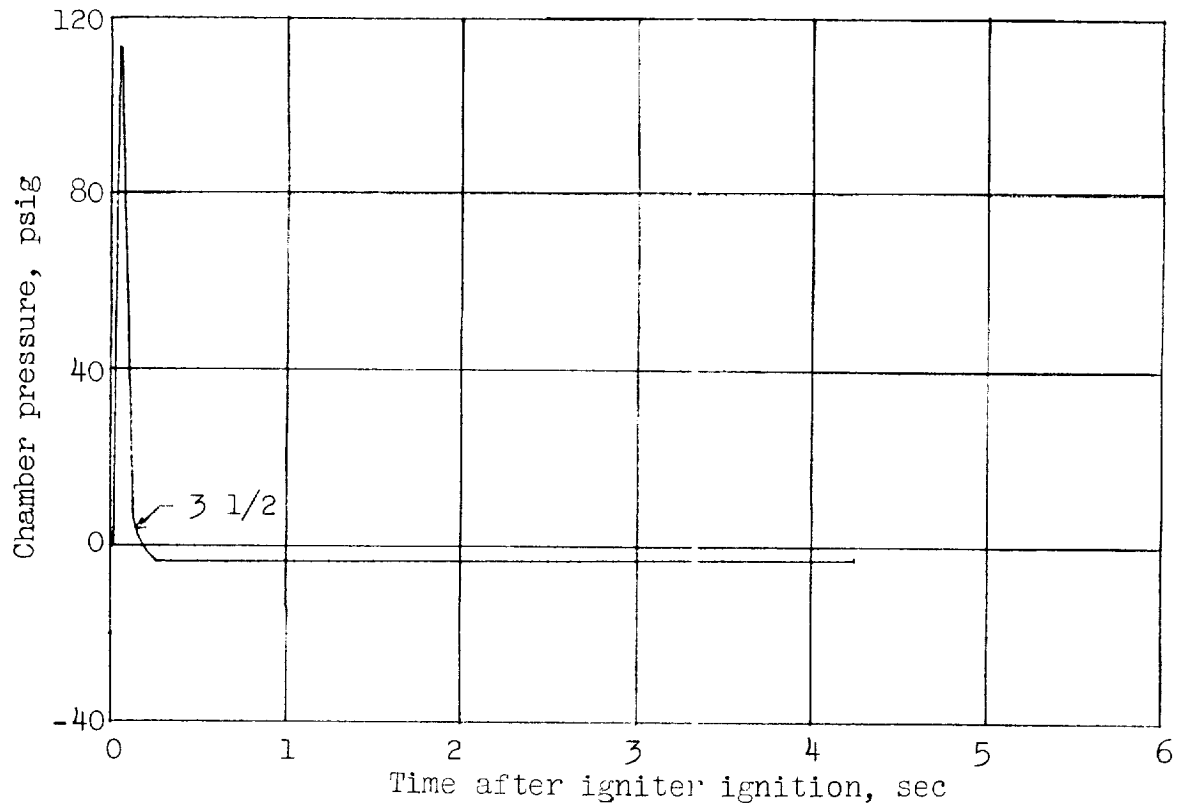


Figure 2.- Sketch of simulated 50,000-pound-thrust liquid-propellant rocket engine having a continuous rocket-type igniter. (Dimensions in inches.)

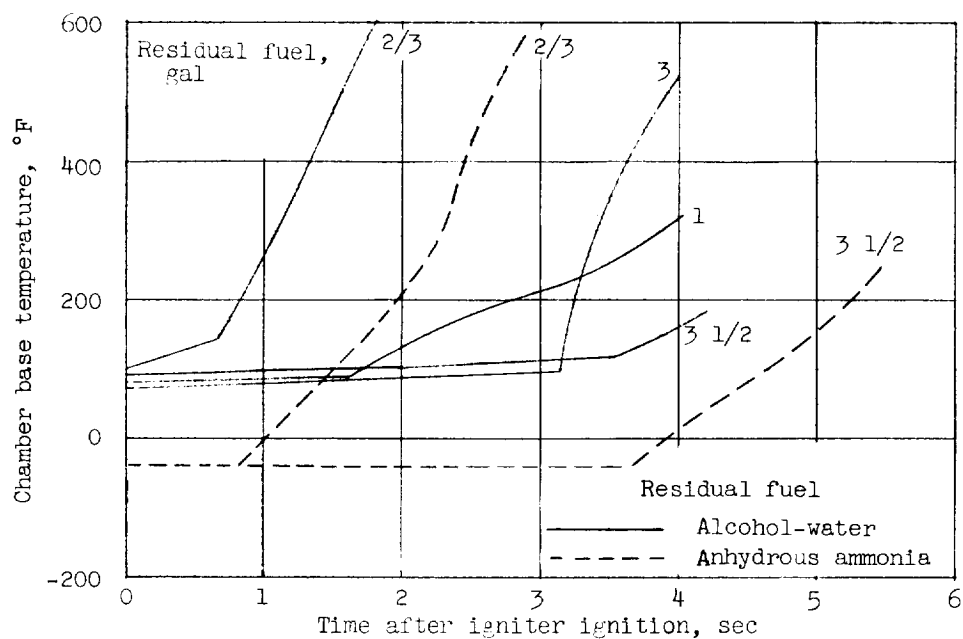


(a) Igniter operating at fuel-rich mixture.

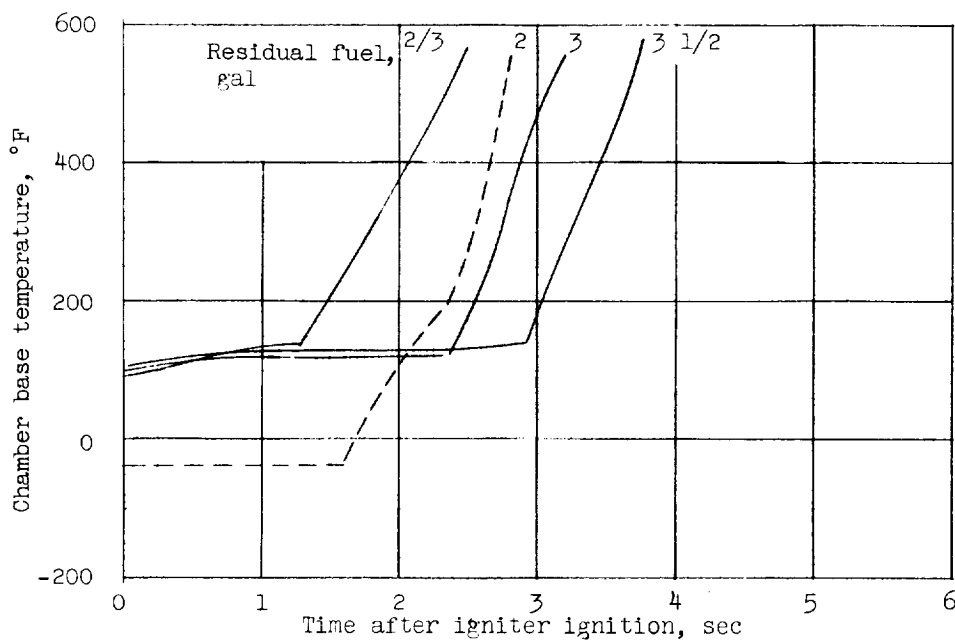


(b) Igniter operating at oxygen-rich mixture.

Figure 3.- Time history of chamber pressure in simulated thrust chamber.



(a) Igniter equipped with supersonic nozzle.



(b) Igniter equipped with sonic nozzle.

Figure 4.- Time history of temperature in simulated thrust chamber. .

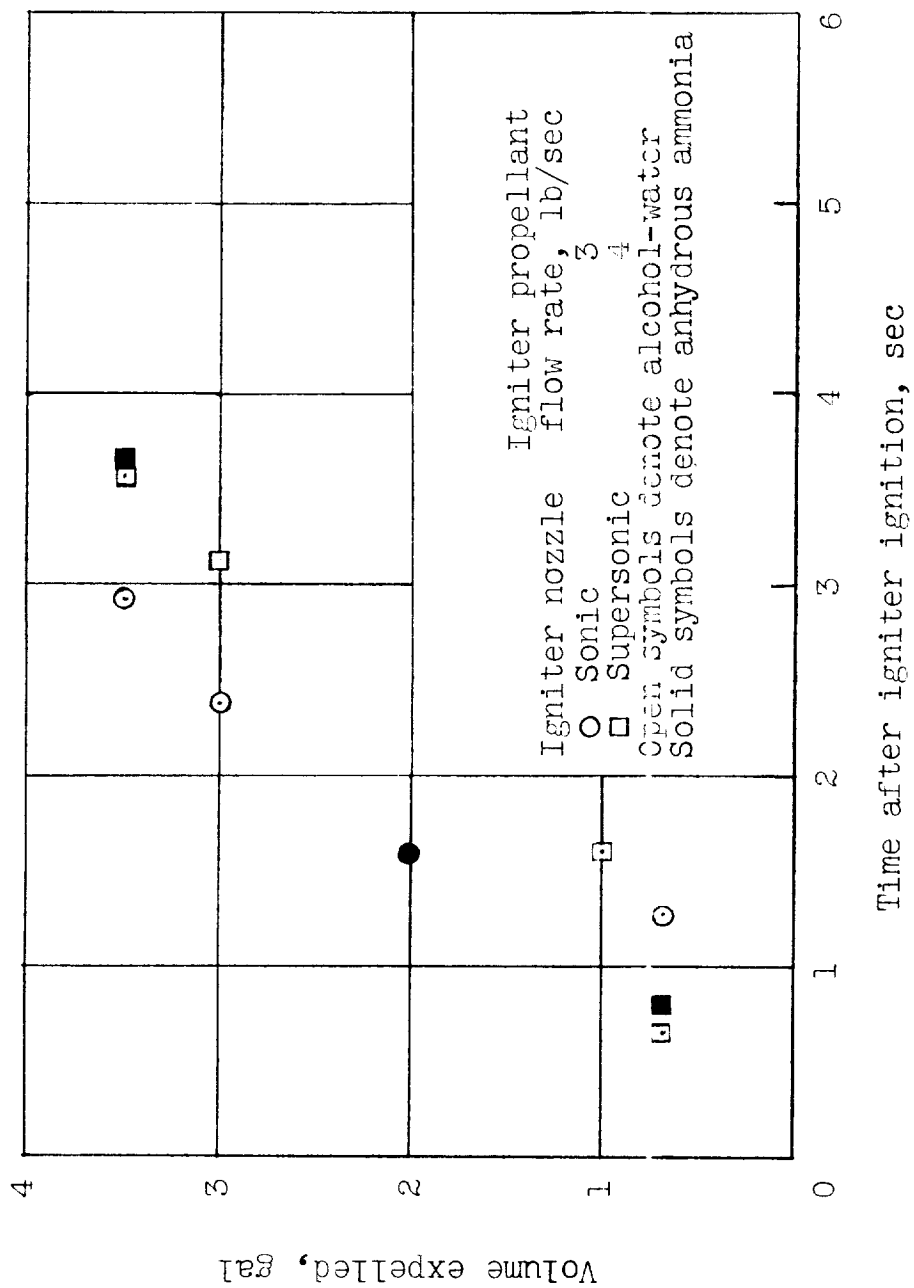


Figure 5.- Time history of residual fuel expulsion from simulated thrust chamber.